# MODULE 14
# RADAR ANALYSIS

## OBJECTIVES

At the end of this module, the student will be able to:

1) Describe the radar reflectivity features associated with non-severe and severe storms
2) Recognize radial velocity signatures associated with rotation, convergence, and divergence
3) List other WSR-88D products and their uses in severe weather analysis

## ANALYSIS OF REFLECTIVITY FEATURES

Analysis of the reflectivity signatures of thunderstorms has taken place since the inception of radar. By investigating the two- and three-dimensional characteristics of reflectivity products, the locations of updraft and downdraft areas can be inferred. Other reflectivity signatures give clues to the storm's strength, organization, and severe weather potential.

*Non-Severe Storms*

Non-severe thunderstorms tend to have **vertically-stacked** reflectivity structures. The low-level echo is generally oval-shaped, with the mid-level echo and storm top directly above the low-level return. Pulse severe storms will have the same general appearance with a few subtle differences. Pulse storms have stronger updrafts, so the storm's first echo appears at a higher altitude than in non-severe storms. The center of high reflectivity, called the **core**, is also at a higher altitude in pulse storms than in ordinary thunderstorms. See Figure 14-1 below for low- and mid-level reflectivity displays showing a pulse storm. The "+" symbol over the mid-level display marks the location of the highest radar echo.

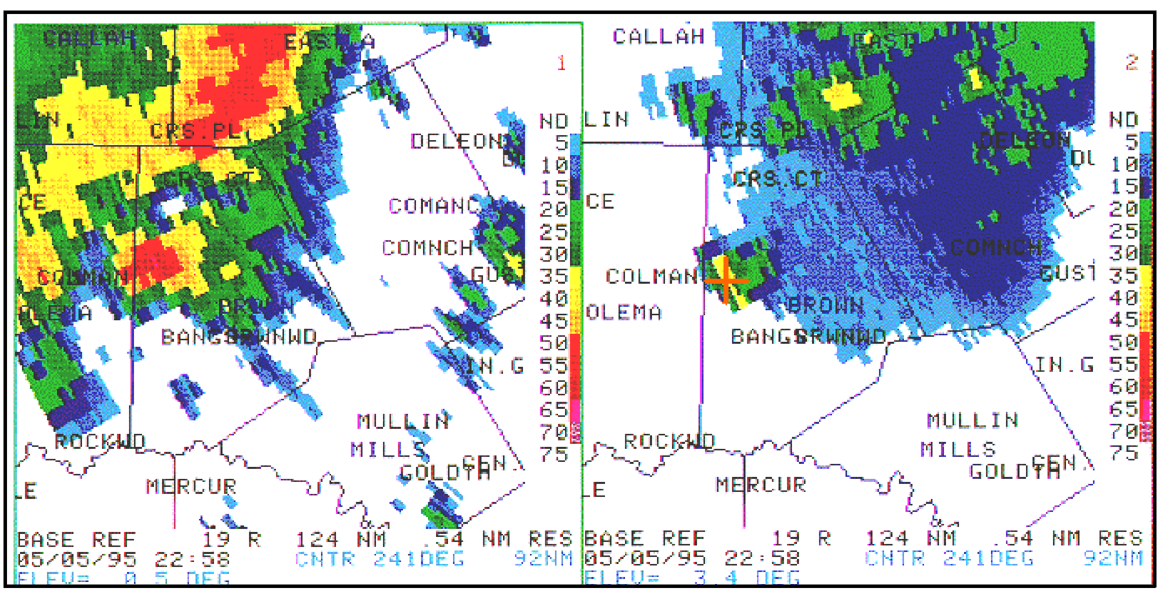


Figure 14-1: Pulse severe storm. Left = low level, right = mid level. Cross hair on right marks storm top

*Severe Storms*

Severe storms have a markedly different reflectivity structure when viewed on the WSR-88D. The low-level echo contains a strong **reflectivity gradient** on the storm's inflow side (usually the south or southeast side). The reflectivity gradient is an area in which the reflectivity changes rapidly over a short distance, and marks the location of the updraft/downdraft interface. The largest hail and/or heaviest rain are found just north and northeast of the reflectivity gradient. At mid levels, the storm has a **weak echo region (WER)**, also referred to as a mid-level overhang. The weak echo region is an area of weaker reflectivity returns partially surrounded by stronger echos at the same level, and topped by stronger echos aloft. The WER suggests a strong, organized updraft. At upper levels, the storm's echo top is located over the low-level reflectivity gradient and mid-level overhang.

Figure 14-2 is a four-panel reflectivity display of a cluster-type severe storm. The lowest slice is in the upper left quadrant (quadrant 1), with progressively higher slices in the upper right, lower left, and lower right quadrants, respectively (quadrants 2, 3, and 4). Note the low-level reflectivity gradient in quadrant 1, as the reflectivity quickly decreases from over 50 dBZ to almost zero reflectivity. Above the gradient, the mid-level overhang is evident in quadrant 3 over the southeast side of the low-level echo.

*Supercells*

Since supercells are the most organized type of thunderstorm, we would expect the reflectivity patterns associated with supercells to be well-organized as well. At low levels, the supercell exhibits a strong low-level reflectivity gradient. The supercell also has an appendage or **hook echo** at the right rear flank of the storm (typically the south or southwest flank of the low-level echo). This hook or appendage suggests the possibility of a well-developed mesocyclone. At mid levels, the WER is more pronouced and may be completely surrounded by higher reflectivities. This configuration is called a **Bounded Weak Echo Region (BWER)**. As with the severe cluster storm, the echo top is located over the BWER and low-level reflectivity gradient on the storm's inflow side.

Figure 14-3 shows a four-panel reflectivity display of a supercell thunderstorm. Quadrant 1 (low levels) shows the strong reflectivity gradient on the south (inflow) side of the echo with the characteristic hook echo on the storm's southwest flank. At mid levels, shown in quadrants 2 and 3, the BWER is evident as a "doughnut hole" in the reflectivity pattern. In the storm's upper levels, the strongest reflectivity is located over the BWER. The storm top is located over the BWER and low-level reflectivity gradient.

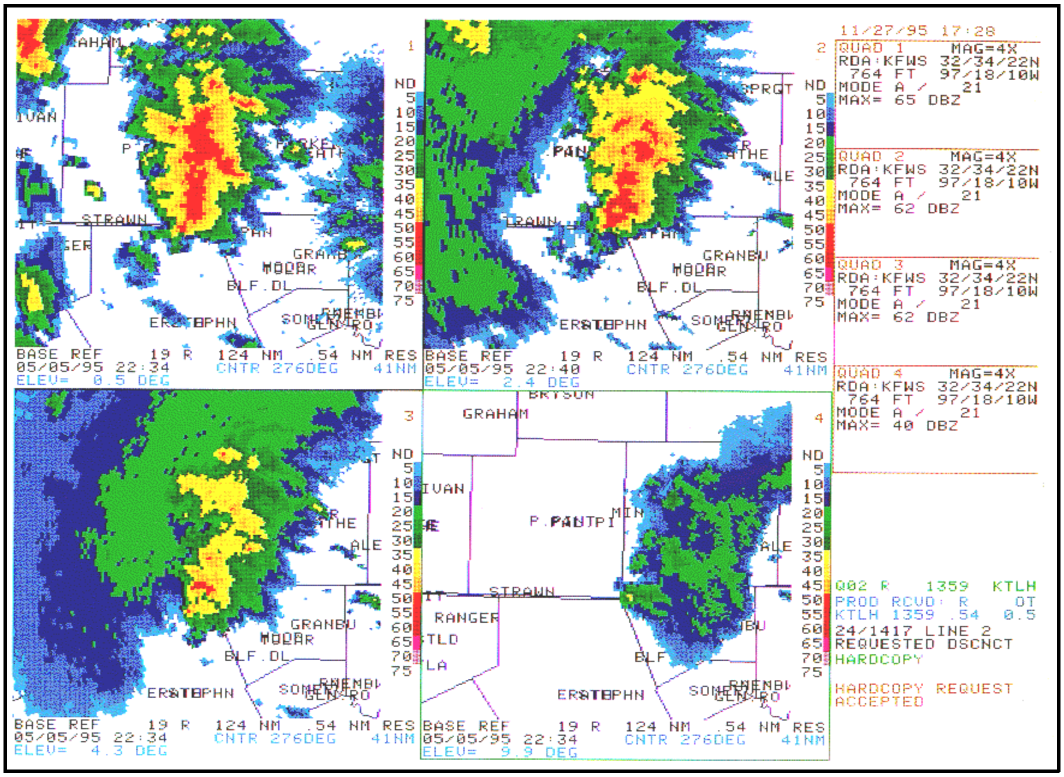

Figure 14-2: Cluster type severe storm seen at 4 elevation angles. Note reflectivity gradient on south side of low-level echo (upper left) with echo overhang (lower right) over southeastern edge of low-level echo.

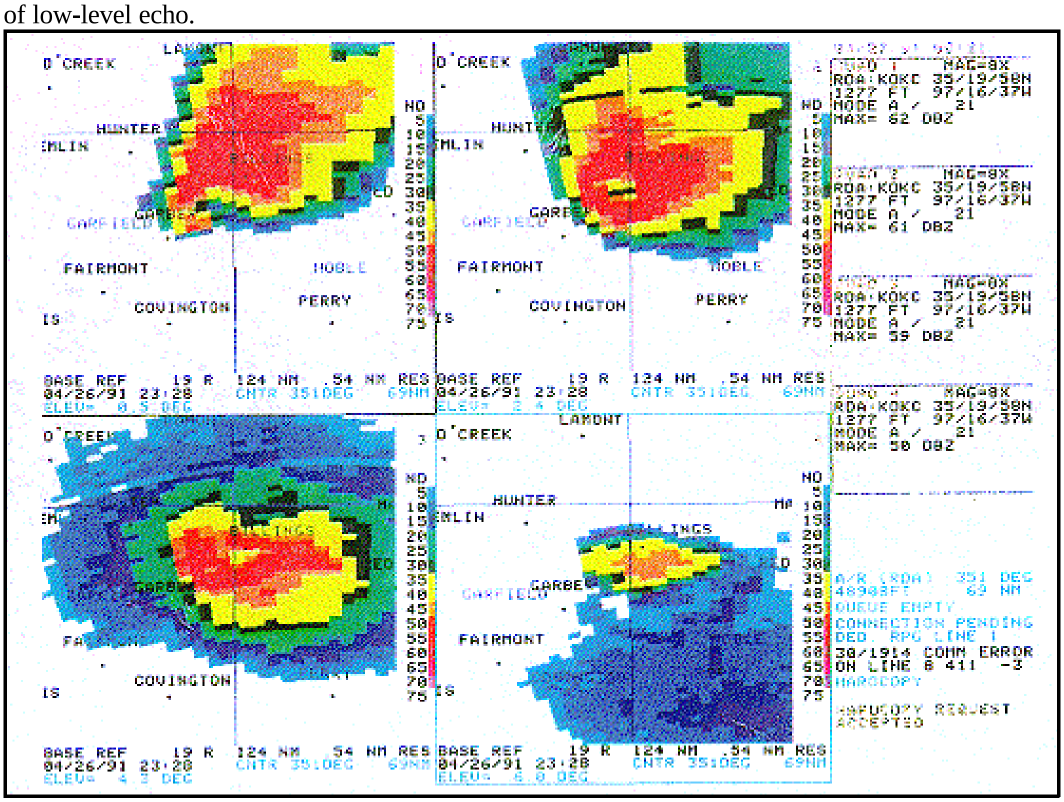

Figure 14-3: Four-panel reflectivity display of a superccell storm. Note hook echo at lower level, BWER at mid levels.

## DOPPLER VELOCITY ANALYSIS

As described earlier, Doppler weather radars such as the WSR-88D can detect motion of targets toward or away from the radar. This motion is referred to as **radial velocity** but does not necessarily depict the actual motion of the targets. When interpreting radial velocity products, it is crucially important that you are aware of the radar's location with respect to the storm. As we will show, similar-appearing signatures can have completely different meanings when viewed from different angles.

Although the radial velocity display shows us only one component of the target's motion, there are some techniques for deriving storm-scale velocity signatures from the radial velocity display. These signatures are based on the relative locations of the highest inbound and outbound velocities. The four primary signatures we will attempt to identify are **convergence**, **divergence**, **cyclonic rotation**, and **anticyclonic rotation**. These signatures are shown in Figure 14-4.

If the area of strongest outbound motion is located closer to the radar than the inbound maximum, then convergence is present. If the outbound maximum is farther from the radar than the inbound maximum, then divergence exists. Looking down the radar beam, if the outbound maximum is on the right with the inbound maximum on the left, then the signature suggests cyclonic rotation. If the inbound maximum is on the right with the outbound maximum on the left, then anticyclonic rotation is present.

## VELOCITY ANALYSIS OF SEVERE STORMS

So, how exactly do these velocity signatures relate to storm structure? Recall from thunderstorm theory that storms with strong updrafts tend to have areas of low-level convergence near their bases. As the air, precipitation, and cloud material produced in the updraft nears the equilibrium level, it rapidly slows down and spreads out near the top of the storm. This in turn produces a strong upper-level divergence signature in the velocity display. Conversely, strong downdrafts (downbursts) will appear as areas of convergence near the top of the storm with divergence in the lower levels. If the storm possesses a mesocyclone, it will be most evident in the storms lower and mid levels as a cyclonic rotation signature.

These velocity signatures are all seen with supercell storms. Figure 14-5 is a four-level velocity display. The quadrants in this figure are arranged as in the reflectivity displays shown earlier. The radar is to the south of the storm, or near the bottom of the page. In quadrants 1 and 2, a cyclonic rotation signature is evident in the low to mid levels of the storm. This represents the supercell's mesocyclone. Convergence is also evident in the lowest elevation slice. In quadrants 3 and 4, strong divergence is evident in the upper portions of the storm. Compare these velocity images to the reflectivity displays shown in Figure 14-3. Note that at low levels, the hook echo is correlated with the mesocyclone circulation. At mid levels, the BWER is coincident with the center of circulation. At upper levels, the echo top is colocated with the center of upper level divergence.

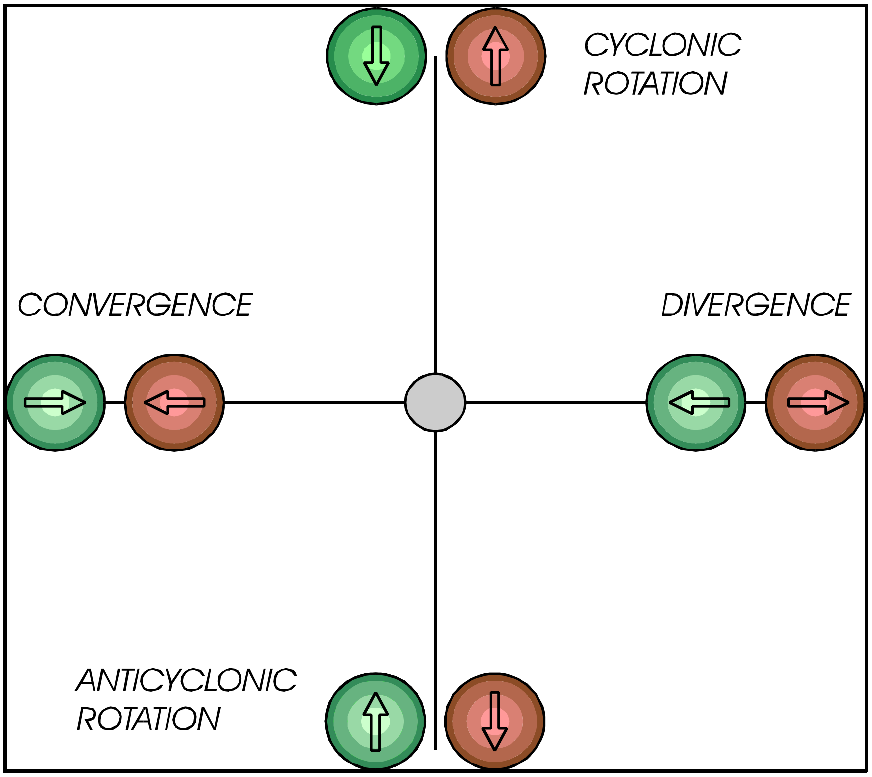


Figure 14-4: Examples of Doppler velocity signatures associated with convergence, divergence, and rotation

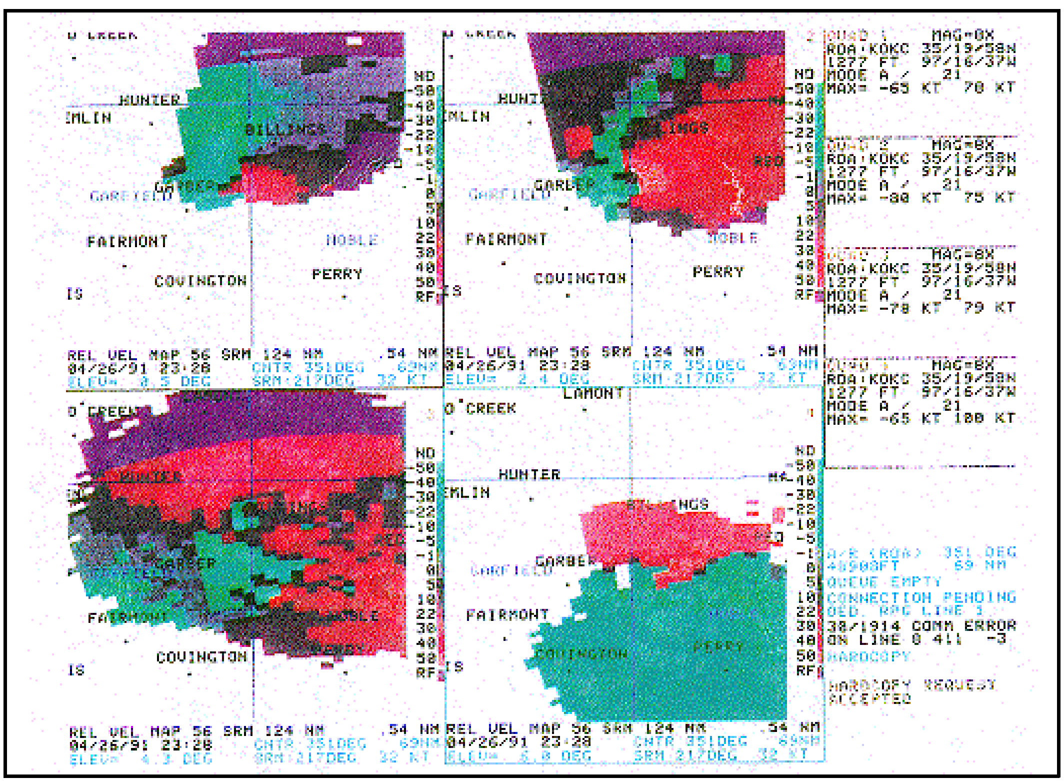


Figure 14-5: Four-panel Doppler velocity images of a supercell. Note cyclonic rotation at lower levels (upper left/upper right quadrants) with strong divergence at upper levels

## WSR-88D ALGORITHMS

The WSR-88D system has an **algorithm**, or computer program, which can detect mesocyclones. The algorithm looks for regions of **balanced, vertically-correlated, cyclonic rotation extending through a depth of two or more elevation angles**. If the rotation is vertically correlated but not balanced, it is termed three-dimensional correlated shear. If the rotation is only at one elevation angle, it is called uncorrelated shear. Examples of WSR-88D mesocyclones (wide yellow circles) and 3-D correlated shear (thin circles) are shown in Figure 14-6 below.

The WSR-88D performs quite well in detecting mesocyclones. On rare occasions, tornado-scale circulations can be observed as well. The **Tornadic Vortex Signature (TVS)**, as it is called, is a small zone of intense cyclonic rotation, in which the maximum inbound velocity is displayed in one radial with the maximum outbound velocity in the adjacent radial. TVSs detected by the WSR-88D are marked by an inverted red triangle.

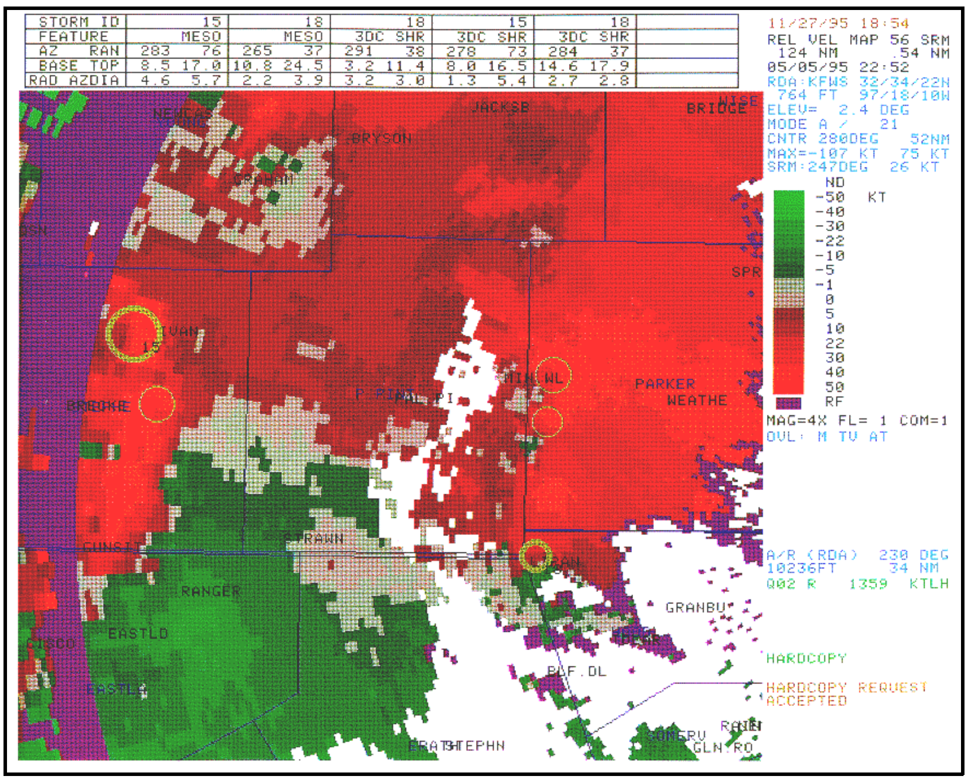

Figure 14-6: Examples of mesocyclones (wide circles) and 3-D correlated shears (narrow circles). Table at top of product displays location of the signatures as well as the base and height of the features.

## OTHER WSR-88D SEVERE WEATHER PRODUCTS

The WSR-88D's computer system has a number of algorithms besides the programs for detecting mesocyclones and TVSs.  Three of the most widely-used products in severe weather operations are the **Vertically Integrated Liquid (VIL)**, the **storm track/forecast**, and the **precipitation estimates**.

The VIL product was originally designed to estimate heavy rainfall.  The VIL algorithm "adds up" the reflectivity in vertical columns throughout the depth of the volume scan and converts it into equivalent liquid water values.  In practice, VIL turned out to be an excellent estimator of large hail.  VIL is measured in units of kilograms of "water" per square meter.  The specific VIL value correlated with large hail depends on the environment in which a storm develops.  During severe weather season VILs above 50-55 kg/m$^2$ are suggestive of hail larger than 3/4 inch in diameter.  See Figure 14-7 for an example of a VIL product.

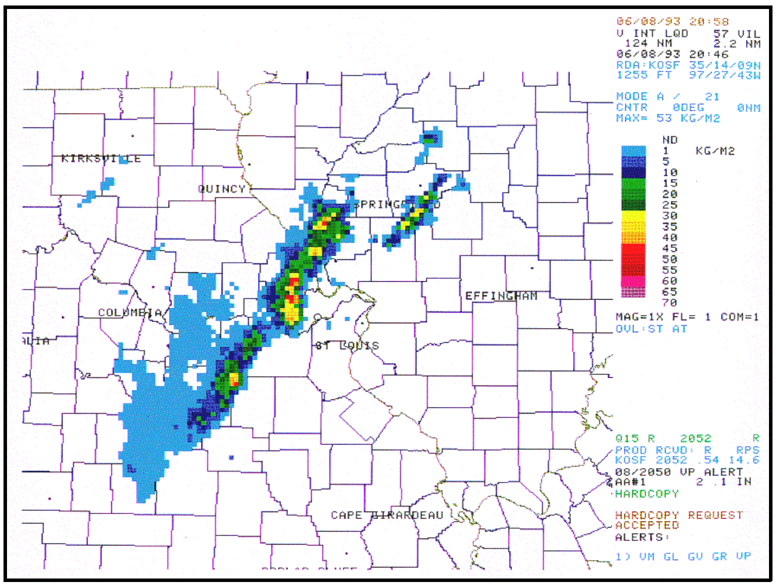

Figure 14-7: Vertically Integrated Liquid (VIL) product.

The WSR-88D has a series of algorithms to identify storms, compute the locations of their centers, and track their movement from volume scan to volume scan.  Although these algorithms are not always reliable, especially when storms are located close together and/or storms are quickly developing and moving, it can give the forecaster an idea of a storm's previous track.  The algorithms also compute forecast positions in 15-minute intervals.  An example of a storm track product is shown in Figure 14-8 on the following page.

The precipitation algorithms used by the WSR-88D are more reliable for determining heavy rainfall than the VIL product.  The algorithms use equations developed by researchers which relate the low-level reflectivity to the rate of rainfall experienced at the ground.  By summing these rainfall rates over a period of time, the total rainfall for an area can be estimated.  The WSR-88D has algorithms which estimate rainfall over a 1-hour and 3-hour period, and for the entire time precipitation was detected.  Figure 14-9 shows a typical precipitation product.

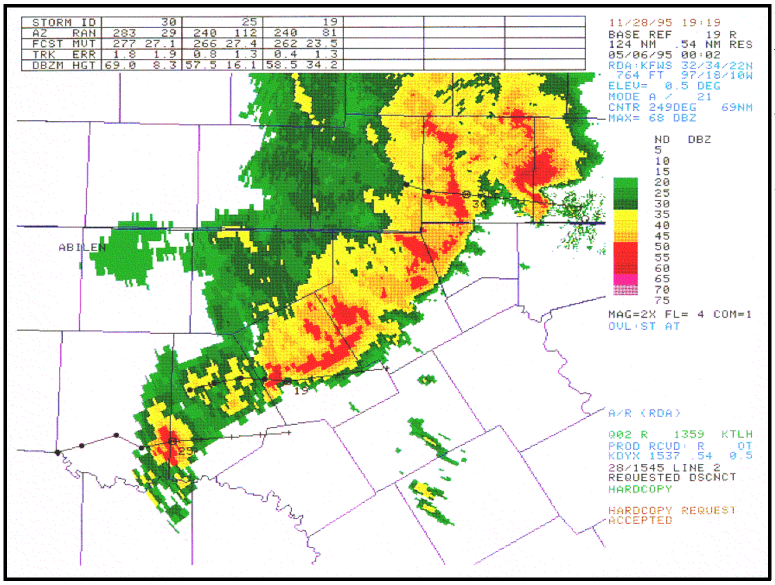


Figure 14-8: Example of reflectivity product with storm-tracking feature added as an overlay. Storm tracks are evident on the two southern storms and the bow-shaped storm. Table at the top of the product identifies storms and provides data on storm tracks.

Figure 14-9: Example of WSR-88D precipitation estimate. This example is for the entire period of precipitation. Other precip estimates calculated by the WSR-88D include one-hour and three-hour totals.